Assessment of the sustainability of agricultural systems- a cross-comparison of the two farming systems in Punjab, India

Abstract

Achieving sustainability in agriculture requires a robust assessment of the system's economic, social, and environmental conditions. This assessment must be supported by scientifically validated indicators that measure all aspects of the system. Hence, the present study aims to develop a composite index to measure and compare the sustainability of conventional and organic farming (OF) systems in Punjab, India. A cross-sectional study based on a primary survey of 348 wheat growers (143 organic and 205 conventional) was conducted to assess the sustainability of two farming systems. A muti-stage random sampling technique was used to collect the data. Based on the OECD index construction methodology, a total of 25 economic, social, and environmental indicators were determined to construct the composite sustainability index (CSI), economic sustainability index (ESI), social sustainability index (SSI), and environmental sustainability index (EnSI). The empirical results of CSI show that organic agriculture is more sustainable than conventional agriculture, whereas ESI is higher in the case of conventional farming (CF). Moreover, the results were statistically significantly different between the two farming groups. The current study's findings will help develop integrated policies to increase agricultural sustainability in Punjab.

Keywords: Sustainability, Assessment, Indicators, Composite sustainability index

1. Introduction

The growing population, rapid pace of climate change, exploitation of natural resources, and shrinking agricultural land have become the major challenge to agriculture in modern times. The concept of sustainability is increasingly garnering support in agricultural policy debates globally. The adverse environmental impacts associated with input-intensive conventional farming (CF) have further questioned the sustainability of the agricultural system and raised the need for a sustainable and resilient agricultural production system (Moreno-Miranda & Dries, 2022a). On the other hand, organic farming (OF) is a holistic approach that enhances the biological and ecological process by avoiding agrochemicals in its production systems. It is a farming practice that creates the slightest ecological disturbance, fits well on socioeconomic, environmental, and ethical grounds, and has the potential to feed the world (FAO, 2015). Organic farming (OF) is generally now seen as an alternative to CF that largely depends upon sustainable agricultural practices, such as crop rotation, inter-cropping, and green manure (Azam & Shaheen, 2019; Singh et al., 2023). However, Rigby & Cáceres (2001) argue that although organic agriculture is generally sustainable, it can also have adverse environmental effects, including nitrates leaching from the field under legumes and ammonia volatilization from livestock waste and accumulation of heavy materials in the soil.

Moreover, OF also exhibits several economic and technical difficulties for farmers that raise the question of sustainability (Moreno-Miranda & Dries, 2022b). Hence, precise measurement and evaluation are inevitable to ensure agricultural sustainability. Sustainability measurement provides a way to understand the long-term impact of current farming practices on the environment, economy, and social well-being.

The review of related literature reveals several measurement (assessment) approaches available to measure the sustainability of the agricultural system. For example, sustainability assessment of farming and environment (SAFE), Lifecycle analysis (LCA), sustainability assessment for food and agricultural systems (SAFA), IDEA, ISAP, MOTIFS, MESMIS (Abdar et al., 2022; Van Cauwenbergh et al., 2007). But, sustainability is a site-specific and dynamic concept that differs from a country's geographical and economic conditions (Zhen & Routray, 2003). Although the dimensions and theoretical framework can be adopted globally, adopting the same sustainability assessment tools and measurement methods for different areas is challenging because priorities or sustainability issues may differ from region to region. Hence, the indicator-based assessment approach has been receiving special attention over the years to measure agricultural sustainability (Berbec et al., 2018; Cristache et al., 2018; Fallah-Alipour et al., 2018; Moreno-Miranda & Dries, 2022a; Pal et al., 2022; ul Haq & Boz, 2020; Zulfiqar & Thapa, 2017). Numerous studies have been conducted worldwide to assess sustainability at different spatial levels, for example, at the regional level (Abdar et al., 2022; Dantsis et al., 2010; Deng et al., 2017; Zulfiqar & Thapa, 2017) and farm level (Bélanger et al., 2012; Berbec et al., 2018; De Olde et al., 2016).

In India, many studies have also been conducted regarding agricultural sustainability assessment. Dasgupta et al. (2021) assessed the sustainability of integrated farming systems in the coastal areas of West Bengal, India. They found that adopting sustainable agricultural practices improves farm-level sustainability in the study area. Häni et al. (2015) measured the farm-level sustainability of tea farms in Tamil Nadu, India, using RISE (Response Inducing Sustainability Assessment) approach. Kareemulla et al. (2017) analyzed state-level agricultural sustainability using 13 indicators with ten year reference period from 2001-2011 in India.

Similarly, Pal et al. (2022) used the indicator-based framework to assess the sustainability in the Indo-Gangetic plains of India. They found a moderate level of sustainability in Haryana and Punjab. Although several studies (Dasgupta et al., 2021; Häni et al., 2015; Pal et al., 2022) have been conducted in India to assess the sustainability from different aspects, the sustainability of wheat farming (wheat being the main cereal crop in the country) could not be assessed. Moreover, the existing literature primarily focuses on the sustainability assessment of only one farming system and lacks critical comparisons between alternative farming systems. Therefore, this study aimed to assess and compare the indicator-based farm sustainability of wheat farming in Punjab, India, under two farming systems: conventional and organic.

The Indian state of Punjab has been considered the most suitable area for this study for multiple reasons. Punjab is suffering from various sustainability issues like declining agricultural growth, over-mechanization, over-exploitation of groundwater, excessive use of agrochemicals, losing biodiversity, and crop burning. Moreover, the state has witnessed a considerable change in cropping patterns in the Green Revolution era (after the 1960s), with a significant focus on wheat-rice monoculture. The adoption of rice-wheat "monoculture" in the state has brought fatigue in the physical and chemical properties of the soil, causing soil degradation. Presently about 60 percent of the geographical area in Punjab is reportedly facing soil degradation (e.g., soil infertility, erosion, water-logging, salinity, toxicity, and alkalinity) due to extractive farming practices.

Similarly, consequences of the Green Revolution in the form of a decline in soil fertility and organic matter, water resources, and increasing demand for inputs to sustain the yield levels have also been reported in Punjab (Government of India, 2017a). The accumulation of nitrate and pesticides to toxic levels in the groundwater is a great cause for concern in the state. Due to these sustainability issues, national and state governments focus on adopting organic farming. But farmers feel reluctant to adopt OF and move from CF to OF. Hence, there is a need to assess and compare the sustainability of the two farming systems, which are more environmentally sound, economically viable, and socially acceptable. The cross-comparison of the two farming systems may provide valuable insights for adopting sustainable agricultural practices. Based on the OECD, (2001) index construction methodology this study adopts a standard set of indicators to assess sustainability. The specific objectives of the study are as follows:

- To determine economic, environmental, and social indicators in Punjab.
- To develop and construct a composite sustainability index (CSI).
- To measure and compare the sustainability of OF and CF systems.

The current study's findings will provide helpful information for policymakers, researchers, and stakeholders in developing policies and plans to increase agricultural sustainability in Punjab. The paper's structure is designed as follows: Section 1 provides the brief introduction, Section 2 provides the study's conceptual framework, and describes the methods and material used in the study. Section 3 focuses on research findings. Further, in section 4 discussion of empirical results has been done. Finally, in the last section, we discuss the study's conclusion and policy implications.

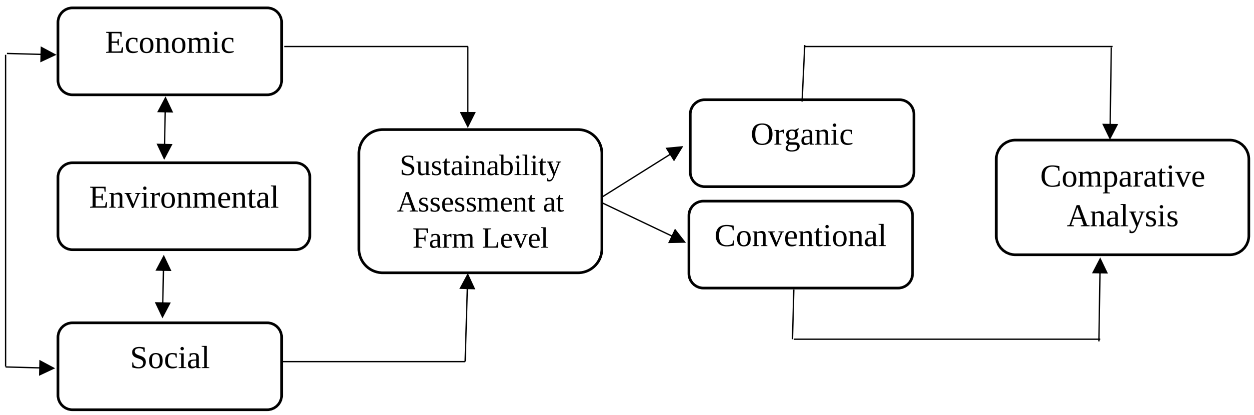
2. Conceptual Framework and Methodology for Data Collection and Analysis

2.1. Conceptual Framework for Sustainability Assessment

Figure 1. represents the conceptual framework for assessing agricultural sustainability in Punjab. The development of the conceptual framework was based on a structured literature review. The sustainability of agricultural systems can be assessed under three economic, environmental, and social dimensions through various indicators and variables. The criteria for selecting the indicators were primarily based on relevance and operational feasibility. After selecting the indicator, the composite sustainability index (CSI) assessed the farm-level sustainability of conventional and organic farming. Based on the CSI of OF and CF, the current study has made a cross-comparative analysis of both farming systems. Moreno-Miranda & Dries (2022a) used a similar aspect for

evaluating and comparing the cross-sectoral sustainability of Ecuador's blackberry, tomato, and tree tomato sectors.

Figure 1. Conceptual Framework of the Study



Source: Author's representation based on literature review

2.2. Methodology for Data Collection

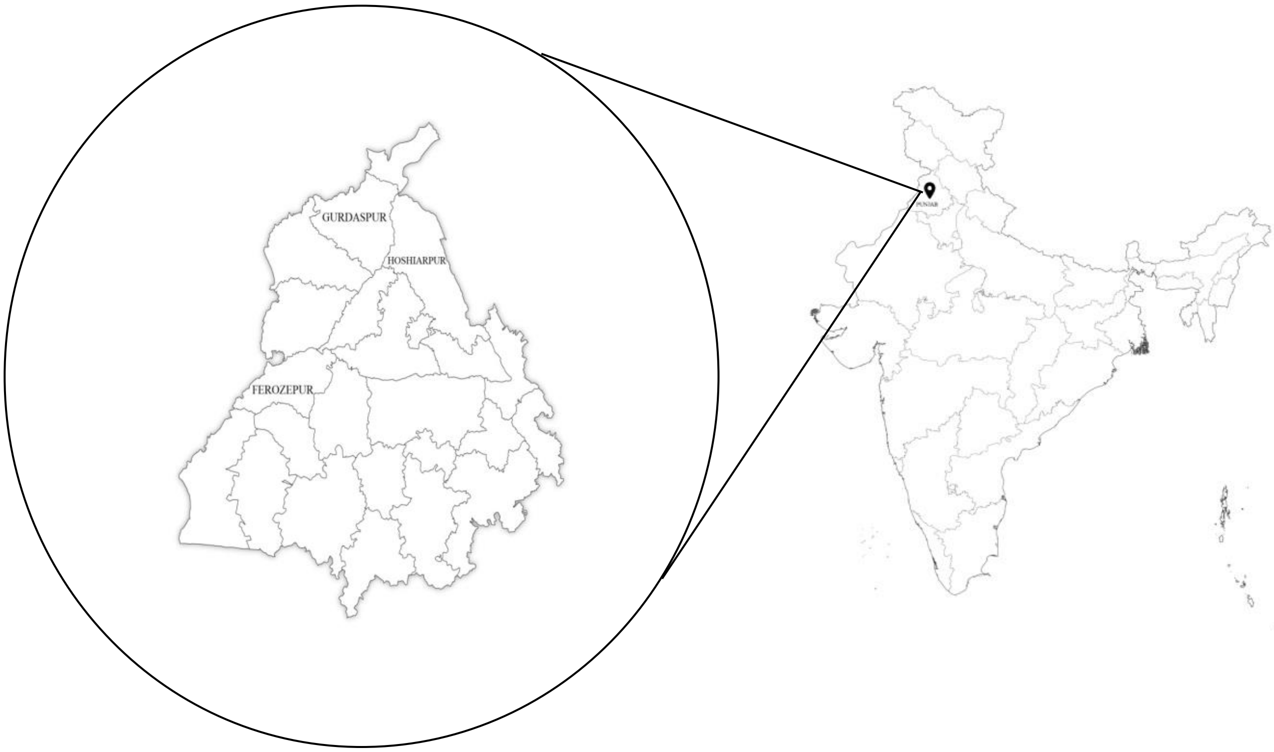
2.2.1. Study Area, Sampling procedure and data collection

A cross-sectional study through multi-stage sampling was conducted in the Indian state of Punjab from July 2021 to September 2021. Punjab is the northern state of India and is also known as the "food bowl of India." It is an agricultural state where the population's main occupation is agriculture. It is the third largest wheat-producing state of India. It has an area of 50,362 square km, which is 1.5 percent of the total geographical area of India. Geographically, it is located at 31.1471° North latitude and 75.3412° East longitude and is divided into three regions: Majha, Malwa, and Doaba. Hence, for the current study, three districts were selected from these three regions: Gurdaspur from Majha, Hoshiarpur from malwa, and Ferozepur from Doaba region. The reason for selecting the mentioned district was the presence of many organic farmers (according to the data available on the PGS[1] website).

Further, for selecting organic farmers, a purposive sampling approach was used to analyze their perspective, and conventional farmers were randomly selected. Three hundred sixty farmers (150 organic and 210 conventional farmers) were surveyed for the initial sample. The final sample includes 348 farmers (143 organic and 205 conventional), as the study aimed to measure the sustainability of wheat farmers. Hence, we exclude farmers not growing wheat crops for this analysis.

[1] Participatory Guarantee scheme (PGS) is a quality assurance scheme that provides third party certification

Figure 2. Location of the Study Area



The data were collected through a semi-structured questionnaire. The questionnaire consists of two sections. In the first section, data related to demographic profiles were asked, and data related to sustainability indicators were collected in the second section. The second section was subdivided into three sections. The information regarding the farmers' economic performance, environment-related activities, and social conditions were collected from the first, second, and third sections, respectively. We contacted each district's Chief Agricultural Officer (CAO) to reach the organic farmers. They helped us organize meetings with OF organizations' representatives, encouraging farmers to participate in the survey. Further, we also coincide our survey visits with member meetings to collect more responses.

2.3. Methodology for Data Analysis

Following the OECD (2008) guidelines, the current study used a composite index approach to measure and compare organic and CF agricultural sustainability. A composite index combines a set of multidimensional indicators for analyzing complex issues and cross-comparative analysis (de Olde et al., 2016; Talukder et al., 2017). To calculate the composite sustainability index (CSI), 25 indicators were determined for the current study from the three dimensions of sustainability: economic, social, and environmental. The indicators were selected based on an analysis of the existing literature and biophysical characteristics of the study area. The description of all the indicators developed for the current study with their measurement and units are presented in Appendix A.

To calculate the composite sustainability index (CSI), firstly, we measured the index under each dimension of sustainability– economic sustainability index (ESI), social sustainability index (SSI), and environmental sustainability index (EnSI). All the selected indicators passed through specific steps such as normalization of data, estimating weights corresponding to each indicator, calculating intermediate indicators under each dimension, and data aggregation. It was assumed that all the dimensions of sustainability play an equal role. Therefore, the composite sustainability index (CSI) was calculated lastly by aggregation of the economic sustainability index (ESI), environmental sustainability index (EnVI), and social sustainability index (SSI) with equally assigned weights. The steps to calculate the composite index are discussed as follows:

2.3.1. Normalization of Data

Due to the multidimensional nature of all the indicators, it represents different units and scales. Hence before calculating the weights of each indicator, it is necessary to make it into a common unit. Therefore, normalization is a technique to get unit-free values of the indicators. In this study, we have used the unitary method to normalize data. It is also called as min-max approach of normalization, where the normal value lies in the range of zero to one. The general formula of the unitary method for positively associated indicators is (X_i-minimum value)/(Maximum value – minimum value), and for negatively associated indicators is (Maximum value – X_i)/(Maximum value – minimum value), where X_i is the actual value of the ith farm.

2.3.2. Assignment of Weights

After calculating the normalized values, principal component analysis (PCA) was performed to obtain the weights of the indicators. PCA is a widely used method in the literature to construct an index (Moreno-Miranda & Dries, 2022a; Pal et al., 2022; Roul et al., 2021, 2023). It is a measure to reduce the dimensionality of the data set with intercorrelated variables. PCA was performed separately for each dimension. Each principal component's eigenvalue and its variance proportion were used to obtain the weights.

2.3.3. Calculation and Aggregation of Intermediate Indicators

To calculate intermediate indicators (economic, social, and environmental), intermediate components were divided by the total weights. In contrast, intermediate components were obtained by multiplying the normalized indicator values with their corresponding weights. Then, the intermediate indicators of each dimension (economic, social, and environmental) were equally weighted. Since it is assumed that all dimensions of sustainability are equally important, each intermediate indicator was assigned an equal weight of 33.33%. Finally, to obtain a composite sustainability index (CSI), the average of equally weighted intermediate indicators was aggregated.

Additionally, spider web diagrams have been used to compare organic and CF systems' economic, environmental, and social sustainability. Further, descriptive analysis was also done, including mean, standard deviation, and frequency analysis. Moreover, a t-test was applied to check the statistically significant difference between the farmer and farm characteristics and the sustainability index of the two farming systems.

3. Results

3.1. Descriptive statistics of farm and farmers

Table 2 summarize the descriptive statistics of variables consisting farm and farmers' characteristics of two farming systems. The mean age of organic farmers are 49.93 years while conventional farmers are on an average 47.31 years of age. The average education of organic farmers is inter school whereas, it is approximately metric for conventional farmers. The statistically significant value of t-test shows a significant difference between education of two farming groups at 1 per cent level of significance. Although, the average farming experience of farmers under OF is lesser than the farmers under CF, however the difference is not statistically significant. The livestock density under OF is higher than CF it is may be because organic farmers prepare fertilizers and pesticides from the livestock wastage e.g., cow urine is used to make pesticides called "jeevamrit". Similarly, distance from farm to nearest market is higher under OF than CF which is 9 km and 7.44 km, respectively. It also indicates the less availability of markets for organic products. Further, the average yield of wheat is quite low under OF. It is 24.40 quintals per hectare in OF while the average yield under CF is 49.72 quintals per hectare. The t- test value indicates a positive statistically significant difference between wheat yield under two farming systems.

Table 1. Farmers and Farm Characteristics

Variable	Units	OF		CF		t-test
		Mean	SD	Mean	SD	
Age	year	49.93	13.08	47.31	12.78	-1.89*
Education	Category (0-5)	3.99	1.18	3.10	1.38	-6.41***
HH size	number	5.28	1.74	5.78	1.90	2.51**
Farming Experience	year	23.36	12.49	25.60	13.44	1.59
Farm size	hectare	4.75	4.77	5.69	4.46	1.89*
Livestock density	unit per ha	2.59	3.90	1.71	2.62	-2.52**
Distance from market	km	9.00	6.68	7.44	2.63	-3.01***
Wheat yield	qtl/ha	24.40	10.73	49.72	7.40	26.20***

Note: education: illiterate = 0; primary = 1; middle = 2; metric = 3; inter = 4; higher & above = 5
Source: Author's own calculation

3.2. Descriptive statistics of sustainability indicators

Table 2 represents the descriptive analysis of all the indicators developed for the study. Regarding the economic indicators, average gross revenue of CF (Rs 10867.7) was higher than OF (Rs 84381.54). Labour productivity of CF was also higher than OF which is 318.44 and 169.86, respectively. Although, gross revenue and labour productivity was higher under CF, however, cost from fertilizer, pesticides and fuel is also high under CF. The cost of manure under OF is higher than CF, it is may be because of higher use of manure under OF than CF. Further the annual amount of loan per hectare per farmer is 91282.11 Rs whereas in OF is 81257.64 Rs. Total average area of farm land with Conventional farmers is higher than organic farmers, i.e., 5.69 and 4.93 ha, respectively. In terms of environmental indicators, organic farmers used organic fertilizers and organic pesticides and conventional farmers used only chemical fertilizers and chemical pesticides, whereas the amount of use of both the inputs is higher under CF. Water use under OF (0.64) is less as compared to CF (0.86). The coefficients of biodiversity, soil health mangement and crop burning for OF are 0.85, 1.49 and 0.22, and for CF are 0.16, 1.00 and 0.69, respectively. Finally, the calculation of social indicators reveal that organic farmers are more socially involved than conventional farmers. The average age of organic farmers is little higher than conventional farmers, i.e., approximately 50 year and 47 years, respectively. The value of farmer development, employment and decent livelihood is 4.84, 509.13 and 1.65, respectively for OF which is greater than CF.

Table 2. Descriptive statistics of sustainability indicators

Indicators	**Mean**		**SD**	
	OF	**CF**	**OF**	**CF**
Economic Indicators				
Gross revenue	84381.54	108671.7	46836.58	14218.95
Labor productivity	169.86	318.44	98.27	50.16
Fertilizer cost	1745.82	5225.55	788.50	1324.70
Pesticides cost	372.72	6527.05	110.52	1845.88
Manure cost	10350.77	807.59	3539.85	1676.10
Fuel cost	11228.42	12424.44	1958.37	2197.87
Distance from nearest mandi (in km)	8.82	7.44	6.50	2.63
loan per ha	81257.64	91282.11	94082.83	111247
Total land in ha	4.93	5.69	4.82	4.45
livestock per ha	2.62	1.71	3.94	2.62
Extension services	3.57	2.99	1.40	1.14
Environmental Indicators				
Fertilizer use	1.11	3.88	0.45	0.90
Pesticide use	11.77	65.27	2.52	18.46
Manure use	20.70	1.61	7.08	3.33
Water use	0.64	0.86	0.29	0.24
Biodiversity	0.85	0.16	0.24	0.27
Fuel use	393.77	496.52	128.34	104.08
Soil health management	1.49	1.00	0.65	0.54
Crop burning	0.22	0.69	0.42	0.46
Social Indicators				
Social involvement	4.61	3.58	1.28	1.06
Risk of abandonment	19.79	30.59	26.08	27.43
Age	49.90	47.31	12.93	12.75
Farmer development	4.84	3.54	1.20	1.45
Employment	509.13	344.16	49.60	34.69
Decent livelihood	1.65	1.34	0.47	0.74

Source: Author's own calculation

3.3. Composite Sustainability Index (CSI)

Table 3 shows the analysis of composite sustainability index. The results of the composite sustainability index (CSI) show that OF is more sustainable as compared to CF since CSI for OF (0.63) is higher than for CF (0.49). The CF appears more sustainable economically as score of ESI under CF (0.49) is greater than OF (0.45), but the difference is not much significant. The environmental sustainability index (EnSI) for CF is very low (0.38), which shows that CF in

Punjab is environmentally very unsustainable. Only 38 per cent farms in CF are environmentally sustainable whereas in case of OF it is 59 per cent. Similarly, the results of Table 3 reveals that the social sustainability index (SSI) for both farming is high, but comparatively, it is greater in the case of OF which means OF is socially more acceptable in study area than CF. Moreover, the results of t-test shows that there is statistically significant difference between CSI, ESI, EnSI and SSI of two farming at 1 per cent level of significance.

Table 3. Analysis of Composite Sustainability index

Sustainability index	OF	CF	t-test
Economic sustainability index (ESI)	0.45	0.49	-4.138***
Environmental sustainability index (EnSI)	0.59	0.38	17.612***
Social sustainability index (SSI)	0.82	0.60	15.547***
Composite sustainability index (CSI)	0.63	0.49	15.664***

Note: *** indicates significant at 1%
Source: Author's own calculation

The results of frequency analysis are shown in Table 4. The reference ranges of sustainability index are taken from the study done by Borzì (2022). The frequency analysis of CSI scores shows that nearly 8 percent of total conventional farms lies under the unacceptable range (0.2-0.4) of sustainability, whereas approximately 88 percent and 4 percent of conventional farms achieved a moderate (0.4-0.6) and acceptable (0.6-0.8) range of sustainability score, respectively. On the other hand, CSI frequency analysis for OF shows that no organic farm is working under an unacceptable range of sustainability. Approximately, 60 percent of organic farms are working under an acceptable range, and approximately one percent of organic farms have achieved an ideal range of (0.8-1.0) sustainability score. Further, the frequency analysis of EnSI indicates that nearly 60 per cent of conventional farms are operating in unacceptable range of sustainability. The SSI score shows that 97 per cent organic farms are working with acceptable and ideal range of sustainability which means OF is socially very acceptable. The ESI frequency analysis reveals that CF is more sustainable since 75 per cent and 11 per cent of conventional farms are working under moderate and acceptable range of sustainability, respectively.

Table 4. Frequency analysis

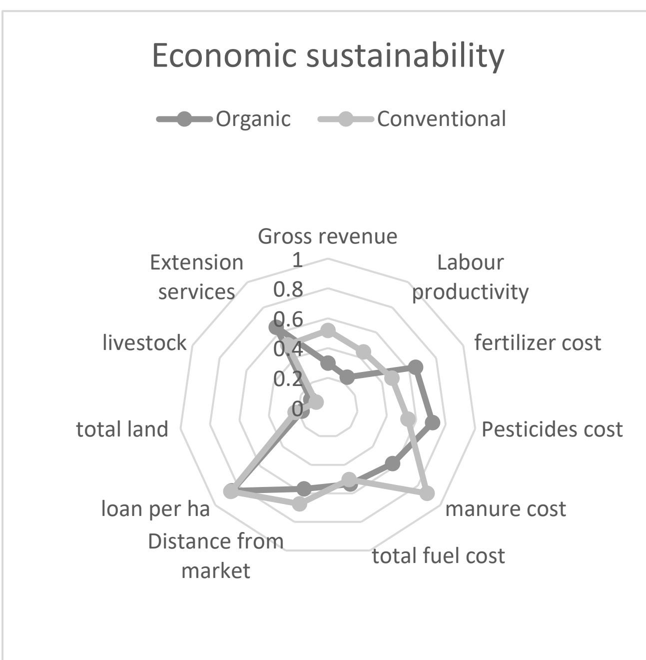
Ranges of sustainability	ESI		EnSI		SSI		CSI	
	OF	CF	OF	CF	OF	CF	OF	CF
Very unacceptable (0-0.2)	0	0	0	4.39	0	0	0	0
Unacceptable (0.2-0.4)	34.26	13.65	3.50	55.12	0	7.80	0	7.80
Moderate (0.4-0.6)	57.34	75.12	47.55	35.61	2.80	39.02	38.46	87.80
Acceptable (0.6-0.8)	8.39	11.21	47.55	4.88	37.76	48.29	60.13	4.39
Ideal (0.8-1.0)	0	0	1.40	0	59.44	4.88	1.39	0

Source: Author's own calculation

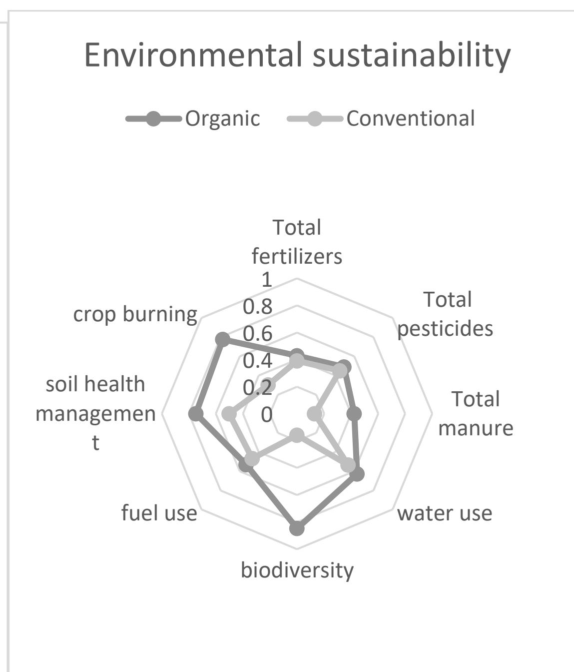
3.4. Sustainability performance based on the dimensions

Next, we studied the relative performance of sustainability indicators from each dimension (economic, environmental and social) through sustainability web. Figure 3 represents the sustainability webs of all the indicators used in current study under three dimensions of sustainability. Sustainability web diagrams are frequently used in literature to compare the sustainability indicators used for sustainability assessment (Bélanger et al., 2012; Dasgupta et al., 2021; Fallah-Alipour et al., 2018; Gafsi & Favreau, 2010; Rigby & Cáceres, 2001a). Figure 3(a), 3(b) and 3(c) represents the sustainability scores of economic indicators, environmental indicators and social indicators, respectively, under two farming systems viz. organic and conventional. Here, the average normalized values of the indicators are used as sustainability scores. The value of sustainability scores lies from zero at the origin to one (furthest from the origin), where closet value to zero indicates worst score and furthest indicates better sustainability score. In figure 3(a), gross revenue and labour productivity under CF scores high than OF. The indicator scores for fertilizer cost, pesticides cost and extension services are high under OF, indicates more sustainability. The indicator score of manure cost under CF shows better sustainability score, it is because conventional farmers rely majorly on chemical inputs and hardly use manure in their farms, that's why average cost of manure under CF is low and its sustainability score is high. The difference between total fuel cost, loan per hectare, total land and livestock are negligible between two farming. The comparative analysis of environmental indicators reveals that sustainability scores of all the indicators under OF is high, see figure 3(b). The larger gap between the mean indicator scores for two farming shows the significance difference between sustainability score, for e.g., biodiversity.

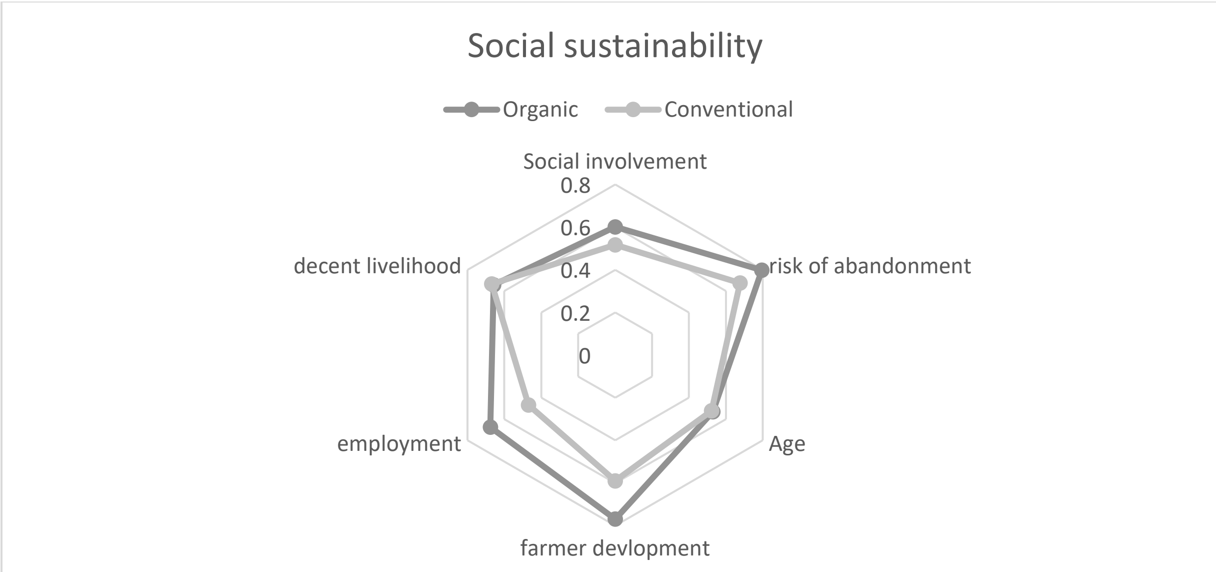
Figure 3. Sustainability performance of economic, environmental and social indicators through spider web diagrams



3(a)



3(b)



3(c)

Source: Author's own calculation

Finally, figure 3(c) represents farmer's social sustainability level, the indicators values of CF and OF are not concentrated around the zero mark. This implies that the social sustainability of both the farming systems is better than economic and environmentally. However, indicator scores under OF is better than CF.

4. Discussion

The current study aimed to determine the sustainability indicators and compare the sustainability of organic and conventional farming in Punjab, India, through the composite sustainability index (CSI). In other words, this study aimed to check which farming system in Punjab is economically viable, environmentally sound, and socially acceptable. The current study's findings indicate that the overall CSI for OF is higher than the CF. Our results align with previous worldwide studies, pointing out that organic farming is more sustainable (Eyhorn et al., 2019; Pacini et al., 2003; Patil et al., 2014). Therefore, to increase agricultural sustainability in Punjab, the focus should be on promoting the OF in the region.

In terms of economic sustainability, organic farming is less economically viable as compared to conventional agriculture since the index score of the environmental sustainability index (ESI) is lower under OF (0.45) than CF (0.49). Although all the indicators under OF (including input costs, viz. fertilizer cost, pesticides cost, and fuel cost) are performing better or almost equal to CF, the ESI value is still lower under OF. The lower ESI value of OF is mainly due to lower gross revenue, lower labor productivity, and a larger distance from the farm to the nearest market. The lower wheat yield under OF is the leading cause of lower gross income. Several studies also observed that lower yield is a significant cause of lower gross revenue in OF (Aulakh & Ravisankar, 2017; Boone et al., 2019; Uematsu & Mishra, 2012).

Further, OF is labor-intensive farming (Rigby & Cáceres, 2001b) and generally requires more labor for manual work. Therefore, due to high labor working hours and lower gross revenue, labor productivity (a ratio of the total output value to total labor hours) under OF is low. Hence, to increase the economic viability of OF, policy focus should be given to increasing the gross revenue of the farmers, and providing a premium on the price of organic products is one of the feasible options. Further, the lower market availability and high distance from farm to organic markets for organic products is other significant reason for OF's lower economic sustainability in Punjab. The unavailability of organic markets is also a major reason for the lower adoption of OF (Best, 2009; Panneerselvam et al., 2012; Patil et al., 2014; Singh et al., 2023). Therefore, policies should focus more on establishing organic markets in the study area.

Further, the current study's findings emphasize that OF is more environmentally sound than CF in Punjab. These findings are consistent with the existing studies on comparative analysis of the environmental sustainability of organic and conventional farming (Berbec et al., 2018; Boone et al., 2019; Cristache et al., 2018; Fess & Benedito, 2018; Pacini et al., 2003). The environmental sustainability index (EnSI) for CF is very low (0.38), lying under the unacceptable sustainability range, indicating that CF in Punjab is environmentally unsustainable. There are several reasons for lower environmental sustainability under CF in the study area. First, conventional farming relies heavily on pesticides and other chemical inputs, which have a negative impact on the environment and harm agricultural sustainability (Bolwig et al., 2009; Dessart et al., 2019; Gafsi et al., 2006; Mlenga, 2015; Willer et al., 2021; Zulfiqar & Thapa, 2017). Second, the prevailing wheat-rice 'monoculture', agricultural intensification and over-mechanization are the significant drivers for biodiversity loss (Berbeć et al., 2020; Gong et al., 2022; Letourneau & Bothwell, 2008; Mondelaers et al., 2009). Third, to maintain soil fertility, conventional farmers heavily use agrochemicals in the soil and hardly adopt any sustainable soil management practices. Further, burning the crop residue in Punjab is a serious threat for environmental sustainability. Despite of various government initiatives to reduce crop residue burning, this practice is still prevalent among conventional farmers (Badarinath et al., 2006; Downing et al., 2022; Sharma et al., 2010; Singh & Kaskaoutis, 2014). The reason for crop residue burning may be the economic factor i.e., it is considered the cheapest method of crop residue management. Therefore, the policymakers should focus on nudging the farmers' behavior towards adopting environmentally sustainable practices by organizing various awareness seminars, workshops and educational programs.

The social sustainability assessment shows a clear difference between the social sustainability of the two farming. The high value of the social sustainability index (SSI) under OF as compared to CF indicates that OF is socially more acceptable. This is because of the high indicator value of social involvement, farmer development, decent livelihood and employment. Most organic farmers are associated with various organizations that regularly organize meetings for ther greater promotion of organic farming. Further, OF is more labor intensive, generating greater employment opportunities. Therefore, to make agriculture in Punjab, socially acceptable government should promote organic farming.

5. Conclusion

Based on the findings, the study concludes that organic farming is more sustainable than conventional farming. Therefore, the need for relevant policy support from the policymakers arises for the more significant promotion of organic agriculture in the region. Although ESI for organic farming is lower than conventional farming, it is mainly due to lower gross revenue, labor productivity, and a larger distance from the farm to the nearest market. Therefore, policy focus should be given to increasing the gross revenue of the farmers, and providing a premium on the price of organic products is one of the feasible options. Further, establishing organic markets in the study area can also help promote organic farming in Punjab. The study has also observed that the EnSI of conventional agriculture is very low, possibly due to the overuse of agro-chemicals and prevailing wheat-rice "monoculture" in Punjab, India.

On the other hand, most organic farmers perform sustainable agricultural practices like crop diversification and intercropping, which are more environmentally sustainable than conventional farming. Therefore, the policymakers should focus on nudging the farmers' behavior towards adopting environmentally sustainable practices by organizing various awareness seminars, workshops and educational programs. Overall, the study concludes that OF is more sustainable in Punjab, thus more focus should be given on promotion of organic farming in the region. Hence, this study provides a way to understand the long-term impact of current agricultural practices on the environment, economy, and social well-being to policymakers for sustainable agricultural development policies.

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Appendix A

Variable	**Definition/Measurement**	**Indicators scores/units**
Economic indicators		
Value of agricultural output (Jane Dillon et al., 2016) (OECD, 2001) (Hayati, 2017)	The total value of agricultural output per hectare	Rs/ha
Labor productivity (ul Haq & Boz, 2020)	Ratio of the total value of output to the total number of labour hours	Rs per hour of work
Fertilizer cost (Waney et al., 2014) (Fess & Benedito, 2018)	Total cost of chemical/organic fertilizers used	Rs/ha
Pesticides cost (NFL et al., 2014) (Fess & Benedito, 2018) (OECD, 2001)	Total cost of chemical/organic pesticides used	Rs/ha
Manure cost	Total cost of manure used	Rs/ha
Fuel cost	Total cost of fuel used (energy, machinery, tubewells)	Rs/ha
Market availability (Smith & McDonald, 1998) (Hayati, 2017)	Total distance from farms to nearest market	Km
Indebtedness	Loans per unit of land	Rs/ha
Land ownership (Praneetvatakul et al., 2001) (Gómez-Limón & Riesgo, 2010) (Horrigan et al., 2002)	Total agricultural land owned by farmers	ha
Livestock density (Ion, 2011) (Majewski, 2013) (Hayati, 2017)	Total livestock units per hectare of land	Unit/ha
Extension services (Bernard et al., 2014) (Fallah-Alipour et al., 2018) (OECD, 2001)	Use of extension programs for dissemination of agricultural technologies	Extension visits: very frequent (5), frequent (4), avoid going (3), avoid going (2), never attend (1)
Environmental indicators		

Fertilizer use (Bausch et al., 2014) (Fess & Benedito, 2018) (Hayati, 2017) (Cukur et al., 2019) (Waney et al., 2014) (Ion, 2011) (Ion, 2011)	amount of chemical/organic fertilizer used per unit of land	Qtl/ha
Pesticide use (Rigby & Cáceres, 2001a) (Pacini et al., 2009) (Gómez-Limón & Sanchez-Fernandez, 2010) (Bausch et al., 2014) (Horrigan et al., 2002) (Hayati, 2017)	amount of chemical/organic pesticides used per unit of land	Lt/ha
Manure use (Rigby & Cáceres, 2001a) (Röös et al., 2019) (Hua-jiao et al., 2007)	amount of organic manure used per unit of land	tonnes/ha
Water use (de Medeiros et al., 2014) (Guttenstein et al., 2010)	Ratio of no. of actual irrigations for a crop to recommended irrigations in the area	no./ha
Biodiversity (Pacini et al., 2009) (Büchs, 2003) (Rigby et al., 2001) (Waney et al., 2014) (OECD, 2001)(Hayati, 2017) (Van Cauwenbergh et al., 2007) (Fess & Benedito, 2018)	Crop diversity will be used as a proxy for biodiversity, a measure to protect the environment and its agricultural systems	Herphindal-Hirschman index
Fuel use (Bausch et al., 2014) (Castoldi & Bechini, 2010) (Halberg et al., 2005) (Pacini et al., 2009) (Hayati, 2017) (Hua-jiao et al., 2007) (Röös et al., 2019)	Total amount of fuel used (energy, machinery, tubewells)	Fuel/ha
Soil health management (ul Haq & Boz, 2020)	Reffering to the adoption of soil management activities e.g. soil testing	Soil testing: yes (1), no (0) Laser land leveling: yes (1), no (0)

Crop burning	If burning crop residues or using them for another purpose, e.g., fodder	Binary: yes (1), no (0)
Social indicators		
Social involvement (ul Haq & Boz, 2020) (Latruffe et al., 2016) (Röös et al., 2019) (Gafsi & Favreau, 2010)	Referring to the diverse network and relation of the farmer with organizations and village	Organizational membership: yes (1), no (0) Social involvement in the village: very high (5), high (4), average (3), low (2), very low (1) Rewards and recognition: yes (1), no (0)
Risk of abandonment (Gómez-Limón & Sanchez-Fernandez, 2010) (Gómez-Limón & Riesgo, 2010) (Hayati, 2017)	Ratio of non-agricultural income to total income	%
Farmers'age (ul Haq & Boz, 2020)	Year passed	in years
Farmer development (OECD, 2001) (Fallah-Alipour et al., 2018) (Hayati, 2017) (Gómez-Limón & Riesgo, 2010) (Majewski, 2013)	Referring to the farmers' knowledge of agriculture through education and training	Farmer education: higher and above (5), inter (4), metric (3), middle (2), primary (1), illiterate (0), Agricultural training: yes (1), no (0)
Employment	An indicator of the social implication of agriculture in the provision and distribution of income.	Working hours/ha
Decent livelihood (Jane Dillon et al., 2016) (Haag, 2016) (Latruffe et al., 2016) (Nijkamp & Vreeker, 2000) (Gafsi et al., 2006) (Pope et al., 2004) (Röös et al., 2019)	Referring to the self-perceived quality of life of the farmer	Fair access to means of production: yes (1), no (0) Have enough time to spend with family and friends: yes (1), no (0)